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Renewable energy in Taiwan

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ABSTRACT

With limited indigenous conventional energy resources, Taiwan imports over 99% of its energy supply from foreign countries, mostly from the Middle East. Developing independent renewable energy resources is thus of priority concern for the Taiwanese government. A medium subtropical island surrounded by the Pacific Ocean, Taiwan has enormous potential to develop various renewable energies, such as solar energy, biomass energy, wind power, geothermal energy, hydropower, *etc*. However, owing to the importance of conventional fossil energy in generating exceptionally cheap electricity, renewable energy has not yet fully developed in Taiwan, resulting from a lack of market competition. Consequently, numerous promotional and subsidy programs have recently been proclaimed by the Taiwanese government, focused on the development of various renewables. This study reviews the achievements, polices and future plans in this area.

Contents

1. Introduction

Since the industrial revolution, traditional fossil energy has been explored and adopted in great amount, so it is gradually depleting (Table 1 [1] shows global reserves and projected years of supply remaining for major fossil energies). In the meantime, owing to the environmental impacts caused by the application of traditional energies, for example the greenhouse effect and environmental pollution, reducing dependence on traditional energy sources and the associated environmental damage is a key goal for entire human being. Renewable energies by definition sustainable and clean, which offer the potential to overcome the gradual depletion of traditional fossil energies and their associated environmental impacts, while simultaneously solving the issues of energy sustainability, economic development, and environmental protection; consequently, the development and application of renewable energies have accelerated during the last decade.

International oil and coal prices, respectively, surged over 80 US dollars per barrel [2] and 70 US dollars per ton [3] this year, and these prices are expected to continue rising in the future as buyers compete for finite reserves. These high energy prices have an enormous impact on Taiwan, which imports over 99% of its energy supply, and thus the development of renewable energy has become a strategy essential to Taiwan's continued economic health.

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Table 1
Global reserves and availability of major fossil energy resources [1].

Category item	Oil (+oil sands)	Natural gas	Coal
Total reserves (end of 2008)	1408 billion barrels	185 trillion cubic meters	826 billion tons
Yield (2008)	29.9 billion barrels	3.1 trillion cubic meters	6.28 billion tons
Available years	47 years	60 years	131 years

Renewable energy is generally considered to include natural energy resources coming from the sun or possessed by earth, such as solar energy (further including solar photovoltaics and solar thermal energy), wind energy, hydropower, geothermal energy, ocean energy (i.e. ocean thermal energy conversion, tidal power, wave energy, *etc.*), as well as renewable biomass energies, such as waste energy, biogas generation, biofuel and so on [4].

A significant body of literature has recently emerged on the subject considered in this study. For example, Wu and Huang [5] reviewed current measures and addressed the perspectives and support mechanisms related to renewable energy in Taiwan; however, this study did not deal with the overall status of renewable energy development in Taiwan. As suggested by its title, the content of Tsai and Chou [6] is concentrated on one field of biomass energy, namely, municipal solid waste (MSW). In fact, considerable potentials do exist for biomass energy development in Taiwan, for example RDF and biofuel. In another study, Chang et al. [7] detailed the development story and installment status of solar water heater (SWH) in Taiwan, but neglected to also provide an international perspective. Yue and Wang [8] assessed wind, solar, and biomass energy sources in rural areas of Chigu in southwestern Taiwan using GIS, a scientific technique that can be extensively applied to investigate the entire Taiwan area, while Tsai [9] reviewed Taiwanese policy regarding renewable energy in several years ago, when the Energy Commission of the Ministry of Economic Affairs did not become the Energy Bureau of the Ministry of Economic Affairs (EBMOEA). Tsai and Chou [10], as its title suggests, reviewed the utilization and development of renewable energy in Taiwan from the perspective of environmental impact, but did not consider the perspective of economic benefit covered in the present study. In another paper, Tsai et al. [11] focused on agrowastes, which are only a minor part of biomass energy development in Taiwan. Finally, Yue et al. [12] examined strategies for increasing the market penetration of wind power in Taiwan. Notably, wind power is the most promising one among the various potential avenues for developing renewable energy in Taiwan.

2. Energy situation in Taiwan

Taiwan is a densely populated island with limited natural resources. Energy supply has increased considerably during the past decade of rapid economic development (Table 2). Total energy supply has increased from 83 million tons of oil equivalent (Mtoe) in 1998 to 128.2 Mtoe in 2008, at an average annual growth rate of 4.5%. Furthermore, Taiwan is highly dependent on coal and petroleum in its energy mix (Table 3), with these energy forms together accounting for 81.9% of total energy supply in 2008. Natural gas and nuclear energy contributed 9.4% and 8.3%, respectively, to total energy supply in 2008, with the remaining 0.4% being supplied by hydropower and renewable energy. Average annual growth in total energy supply is projected to reduce to 2.1% during the next two decades.

Table 2 shows that Taiwan's energy self-sufficiency ratio has reduced from 1.5% in 1998 to just 0.7% in 2008. Taiwan thus confronts an increasingly serious challenge in terms of security of energy supply. Notably, Third National Energy Conference was convened in 2009 to formulate strategies and measures in response to the impact of the United Nations Framework Convention on Climate Change and to seek a balance among economic development, energy supply, and environmental protection in Taiwan. The development and application of renewable energy resources and technologies are becoming vital in the management of energy supply and demand. The Bureau of Energy under the Ministry of Economic Affairs (BEMOEA), which aims to formulate and implement the national energy policy, has been positively promoting research and development on renewable energy. Wind power generation, solar photovoltaic energy, solar thermal energy, geothermal utilization, ocean energy and biomass energy are the main focus of development. As a result of these efforts, Taiwan's energy self-sufficiency is expected to increase from 1% in 2003 to 4% in 2020.

3. Renewable energy in Taiwan [13]

Compared the rest of Southeast Asia, Taiwan equals Southeast Asian nations in terms of developing biomass energy and

Table 2
Energy supply [13].

Item	1998		2003		2008		1998, 2008
	Mtoe	%	Mtoe	%	Mtoe	%	Growth rate %
Total	83.0	100	110	100	128.2	100	4.5
Indigenous	1.5	1.8	1.1	1.0	0.8	0.7	−4.1
Imported	81.5	98.2	108.9	99.0	127.4	99.3	4.6

Table 3
Energy supply by resources [13].

Item	1998		2003		2008		1998,2008
	Mtoe	%	Mtoe	%	Mtoe	%	Growth rate %
Coal	24.5	29.6	35.8	32.5	41.6	32.4	5.2
Petroleum	42.4	51.1	55.8	50.8	62.5	49.5	4.2
Natural gas	5.8	7.0	8.0	7.2	12.1	9.4	8.6
Hydropower	0.5	0.7	0.3	0.2	0.4	0.3	0.3
Nuclear	9.6	11.6	10.1	9.2	10.6	8.3	1.2
RE (excluding hydropower)	–	–	0.1	0.1	0.2	0.1	109

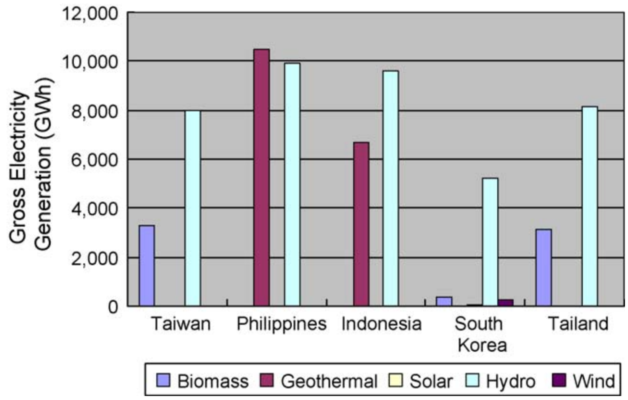


Fig. 1. Comparison of RE gross electricity generation among countries of Southeast Asian for 2006 [14].

hydropower, as shown in Fig. 1. Notably, hydropower is the most popular renewable energy in the region. Geothermal energy enjoys high application in certain countries as well, such as the Philippines, Indonesia, and Japan (not shown in the table), all of which are located at fault-lines along the Pacific Rim, Taiwan should share the same geographic advantage in terms of developing geothermal energy. Furthermore, significant potential also exists in Taiwan to develop solar energy and wind power, respectively, given that it is a subtropical island adjacent to a famous ''wind tunnel'' in the form of the Taiwan Strait.

Production cost analyses of various renewable energies in Taiwan are listed in Table 4. In this table, solar water heater has the highest economic efficiency, followed by biomass and wind power, and finally PV is the least efficient. These economic realities are reflected in the status of different development strategies in Taiwan. For example, solar water heater has enjoyed successful development and achieved a strong international reputation, yet the development of PV remains very limited. On the other hand, wind power and biomass energy have been prioritized in government planning. Finally, owing to environmental considerations and the relatively high production costs, small hydro power and geothermal power projects have received little development attention.

To encourage people to use renewable energy, the Ministry of Economic Affairs (MOEA) promulgated three incentive measures for three RE applications in 2000, which including solar hot-water system, solar PV demonstration system, and wind power demonstration system. Additionally, the Taiwan Power Company issued interim measures regarding the purchase of electricity generated from renewable energy sources in November 2003. After implementing these measures and subsidies, the promotional status of renewable energy at the end of November 2009 was as follows. Please also see Table 5, which illustrates the targets and strategies for each kind of renewable energy in terms of near future.

- For solar water heater (SWH), the total area of solar collectors installed nationwide reached 1.78 million m^2 at the end of 2008.
- Currently, the total installed capacity of solar photovoltaic systems is 6.7 MWp. Capacity is expected to increase to over 21 MW by the end of 2010.
- Total installed capacity of wind power systems is 353 MW, with a projected target of 2159 MW by the end of 2010.
- Regarding geothermal energy, the Bureau of Energy (BOE) is working with local governments to develop geothermal power generation projects with multi-purpose utilization. The target for the geothermal power generation is 50 MW by 2010.
- Regarding small hydropower, total installed capacity is around 166 MW. It is estimated that another 200 MW will be economically feasible in the future.
- Regarding biomass power generation, total installed capacity is approximately 814.5 MW.

To establish a legal basis for promoting renewable energy and to foster its sustainable utilization, the ''Renewable Energy Development Bill'' has been approved by the Legislative Yuan in June 2009.

4. Solar thermal energy

In Taiwan, the only commercially available solar thermal product is solar water heater (SWH), of which 98% is used for domestic purpose. Taiwan is a subtropical island located between the latitudes of 22° and 25° North and the longitudes of 120° and 121° East. Annual sunshine is in the range of 1500–2200 h for most parts of the island, and even reaching 2500 h in the southernmost region. As illustrated in Fig. 2, the average solar irradiance in Taiwan is 716–1027 kcal/day m^2, and thus solar energy resources in Taiwan are so abundant as to make the development of solar energy extremely practical compared to most location around the world.

To encourage more people to install solar water systems, the BEMOEA has implemented ''Measures for Promoting Solar Hot-Water Systems-2nd phase'' since 2000. The subsidizing rate is based upon type and area of collectors installed in a solar hot-water system, as follows [16]:

- Glazed Flat-Plate Collector: 2250 NT dollars per square meter;
- Evacuated-Tube Collector: 2250 NT dollars per square meter;
- Unglazed Flat-Plate Collector: 1500 NT dollars per square meter.

These rates are applicable to users on the main island of Taiwan. On the smaller islands there is an additional subsidy of 2250 NT dollars per square meter owing to the additional transportation expenses. Generally, the subsidy covers 20–30% of the total cost of a solar hot-water system (including installation cost). Since the launch of this incentive scheme, the number of SWHs installed has increased markedly. From Fig. 3, the accumulated area of solar collectors installed reached 1.78 million square meters at the end of 2008. Currently, approximately 433 thousand families have

Table 4
Production cost analysis of renewable energy resources in Taiwan [15].

	Solar water heater	Solar photovoltaics	Wind power	Small hydro power	Geothermal power	Combustible biomass power
Conversion efficiency (%)	50	10–20	20–40	90	6–12 (binary) 15 (flash)	30–34
Energy production cost[a] (US $/kWh)	2.0	14.1	5.0	5.3	6.3	Biogas: 3.9 Incineration: 4.2 Gasification: 6.1

[a] Methodology of energy production cost: (1) Interest rate = Ir. (2) Depreciation years = n. (3) Capital recovery factor (CRF) = $Ir(1+Ir)^n/((1+Ir)^n-1)$. (4) Annual amortization cost (AC) = Co (total cost) × CRF. (5) Annual maintenance/operation fee (AF) = total cost (Co) × annual maintenance and operation cost ratio (AR). (6) Energy production cost = (AC + AF)/energy production = Co(CRF + AR)/energy production.

Table 5
Current status, future targets and promoting strategies for RE in Taiwan.

Year	2009 Current status [13]		2010 Future targets		Promotional strategies for achieving Targets Set for each RE by 2010
Renewables	Installed capacity (MW)	Share of total (%)	Installed capacity (MW)	Share of total (%)	
1 Hydropower	1937	3.9	2168	4.22	To promote five hydropower generation projects by Taiwan Power Company, with total installed capacity of 171 MW To promote six hydropower generation projects by private sector, with total installed capacity of 72 MW To provide the private sector with information for small hydropower generation in situations where there is no impact on the ecological environment
2 Wind Power	353	0.7	2,159	4.20	To remove obstacles for projects in progress To identify potential wind sites To review incentive measures for enhancing the development of wind energy
3 Solar Photovoltaics	6.7	0.00	21	0.04	To promote demonstration projects, including the "Solar City", and public buildings To establish solar PV systems for remote areas To develop PV industries
4 Geothermal	–	–	50	0.10	To assist local government in exploring geothermal energy To assist local government in developing the geothermal project in the aspects of finance and technology
5 Biomass	814	1.65	741	1.44	To promote the district RDF (Refuse Derived Fuel) system for waste treatment and power generation To promote sales of biogas power at premium rates To assist private enterprises in establishing power plants fueled by agricultural waste such as rice husks To promote industrial waste RDF-fueled power generation, especially in paper mills
Total	3110.7	6.25	5139	10.0	
Target share for renewable energy in terms of installed capacity of the total		6.25%	10.0%		

installed SWH in Taiwan, representing an installation rate of around 5%; that is, 5% of families have installed SWH. Solar water heaters thus are the most notable success story in RE development in Taiwan.

Currently, Taiwan has a sophisticated SHW industry, comprising: 52 manufactures, 519 retailers, and 2500 employees, with annual sales of 120 thousand square meters, equivalent to 20–40 million US dollars or ten thousand new users. Notably, 96% of qualified installers/dealers are located in western Taiwan. Metallic (stainless or copper) flat-plate solar collectors account for 78% of SWHs, with the remaining 22% being evacuated-tube collectors. Almost all metallic flat-plate solar collectors are produced domestically, while some evacuated-tube absorbers are imported. Most SWHs are permanently connected to an auxiliary electric heater.

5. Photovoltaics [19]

BEMOEA initiated the practice of "Measures for Subsidizing Photovoltaic Demonstration Systems" in 2000. Besides offering qualified applicants subsidized rate of 150 thousand NT dollars per

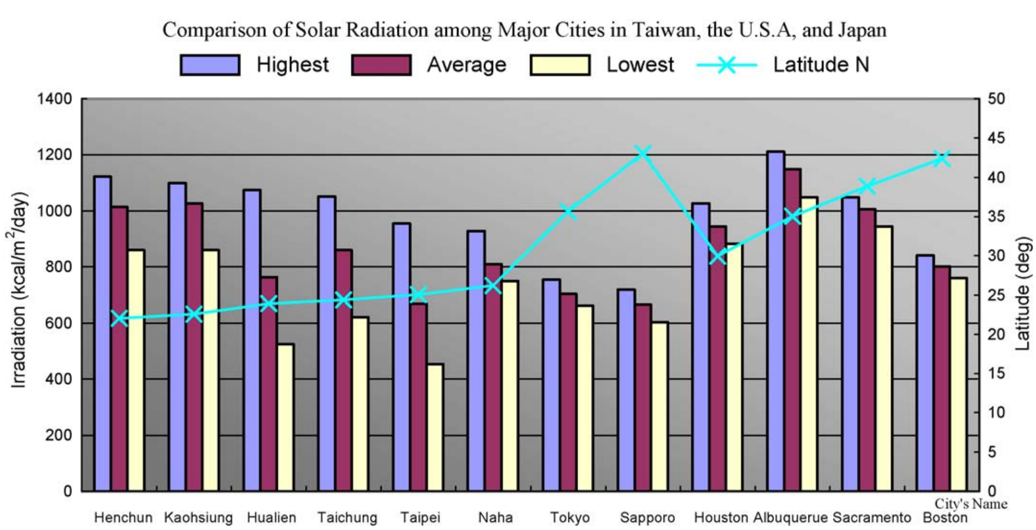


Fig. 2. Comparison of solar radiation among major cities in Taiwan, the U.S.A., and Japan [17,18].

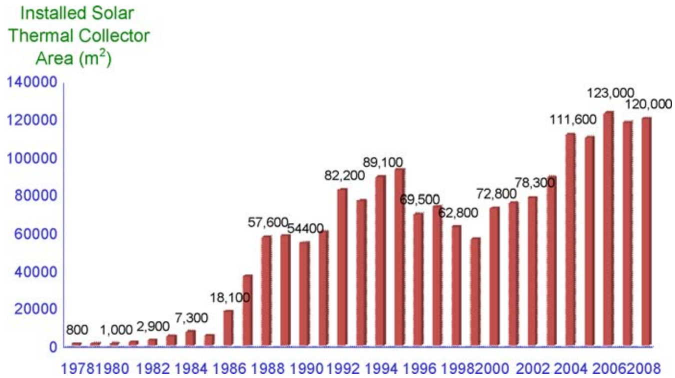


Fig. 3. Statistical diagram of installed area of solar thermal collector in Taiwan (1978–2008) [18].

kWp (providing the subsidy does not exceed 50% of the total installation cost), the government further provides full subsidy (up to 10 kWp in each case) to juridical persons, who are selected from public organizations, schools, or hospitals, *etc.* Most domestic PV systems are focused on power supply, testing, and research. Over 400 demonstration systems have been built in Taiwan as a result of this government incentive program, the total capacity of which has exceeded 6.7 MWp to date.

Regarding the PV industry, there are several internationally famous companies focused on different products in Taiwan, including Sino-American Silicon Products Inc. for silicon wafer, Motech and E-Ton Dynamics for solar cell, and Photonic Energy Semiconductor Co. Ltd. for modular package. Notably, Motech ranks sixth manufacturer of solar cell/module in the world, with annual yield of 176.4 MWp in 2007 [20]. Statistically, there are 7 manufacturers of silicon-crystal in upstream, 45 manufacturers of cell-module in middle stream, and 29 manufacturers of system application in downstream. These companies have constructed a complete manufacturing chain for the PV industry in Taiwan. The totally annual yield is 3.1 billion US dollars, ranked fourth in the world. However, since PV electricity generation is more costly than traditional power generation, PV application currently remains in the demonstration stage in Taiwan, even though a fixed feed-in tariff of 2 NT dollars per kWh has already been implemented by government.

In terms of R&D, government goals for PV during the next decade are as follows:

(1) Developing mass production technology with high efficiency and reliability to reduce PV production cost.
(2) Combining PV module with construction materials to enhance its market application.
(3) Promoting the combination of new technology and architecture design to merge PV systems into real living circumstances.

6. Wind energy [13]

Taiwan is estimated to have wind power potential of 1000 megawatts on land and 2000 megawatts at sea. To promote wind power generation, the Taiwanese government initiated a 5-year wind energy demonstration project in 2000 and simultaneously provided a technical support to domestic industry via specific research organizations, for example, EEL (Energy and Environment Laboratories) of ITRI (Industrial Technology Research Institute). In March 2000, the BOE announced "Measures for Subsidizing Wind Power Demonstration Systems", which regulates that all candidates must be reviewed for possible subsidy eligibility at a rate of no more than 16,000 NT dollars per kWp, with the subsidies received not to exceed 50% of the total cost of each wind farm project. Currently, three demonstration wind driven generation systems have been set up under this program:



Fig. 4. Asia's biggest wind farm, with 49.8 MW, installed on the western coast of Miaoli County, Taiwan [21].

(1) The first one is "Mai-Liao Wind Power Demonstration System", located in Mai-Liao, Yunlin County, operated by Formosa Heavy Industries Company, completed in November 2000, with capacity of 2640 kW.
(2) The second one is "Chungtun, Penghu Wind Power Demonstration System", located in Chungtun, Penghu County, operated by Taiwan Power Company, which was completed in October 2001 and has capacity of 2400 kW.
(3) The third one is "Springwind Wind Power Demonstration System", located in Chupei, Hsinchu County, operated by Tien Long Paper Mfg. Co., with capacity of 3500 kW.

The total capacity of above three wind power systems is 8540 kW, which is equivalent to the utility usage of 3000 families.

As shown in Table 5, wind power has been prioritized in the efforts to achieve projected targets of renewable energy nationally, because it comprises a major share of total target capacity. Numerous related projects are being implemented by domestic and international companies. For example, cooperated with InfraVest GmbH, Taiwan Power Company just finished a wind power project of 49.8 MW along the coast of Miaoli County in June 2006, which is the biggest single wind farm in Asia so far [21] (see Fig. 4). Wind farms of more than 600 MW will be further erected along the western coast of Taiwan during the next 3 years in accordance with the plans scheduled by BOE [22]. Therefore, it seems likely that existing targets for wind power electricity development, and by extension renewable power generation, that is, 2159 and 5139 MW, respectively, will be achieved by 2010.

The international development trend in the area of wind power systems, namely towards the development of off-shore wind farms comprising large-scale wind turbines, which minimizes land utilization and maximizes economy is one potential direction for the development of wind energy applications in Taiwan, an island nation surrounded by the Pacific Ocean that has excellent potential for off-shore wind farm construction. In the near future, the Taiwan Power Company will install 100 large-scale off-shore wind turbines along the western coast of Taiwan and on remote islands, where the wind speed frequently exceeds 5 m/s.

7. Biomass energy

Biomass energy is widely used in Taiwan, including biogas (methane) from animal waste and fuel energy from the burial, gasification, breaking-down, and fermentation of household, industrial and agricultural garbage. Since biomass energy makes

Table 6
Developing status of biomass energy in Taiwan (2009).

Item	Installed capacity (kW)	Energy value (million ton oil equivalent (Mtoe))
Power Generation Application[a]		
Garbage Incineration[b]	450,000	0.086
Waste Plastic and Rubber	33,700	0.059
Paper Industry Waste	8,000	0.001
Sugar Cane Bagasse	27,500	0.049
Methane[c]	22,900	0.031
Sludge	1,400	0.003
Others	58,700	0.046
Summation	602,200	0.275
Item	**Processing capacity**	**Energy value (million ton oil equivalent (Mtoe))**
Thermal Application		
Black Liquid/Paper Industry Waste	0.600 million tons/year	0.195
Waste Tire	0.015 million tons/year	0.012
Sugar Cane Bagasse	0.527 million tons/year	0.068
Rice Husk	0.045 million tons/year	0.014
Methane	3.160 million m^3/year	0.005
Petroleum Cokes	0.030 million tons/year	0.022
Refuse Derived Fuel (RDF)	0.020 million tons/year	0.008
Waste Solvent	0.020 million tons/year	0.016
Summation	1.257 million tons/year 3.160 million m^3/year	0.340

[a] According to the data from 2009.
[b] Currently, there are 21 large-scale garbage incinerators in Taiwan.
[c] There are four garbage burial fields, 30 small-and-medium pig farms, one large-scale pig farm and three industrial wastewater processing factories.

a dual contribution to energy supply and environmental protection, it is generally recognized as one of the most popular renewable energies in the world, comprising approximately two thirds of total renewable energy use. The development potential of biomass energy in Taiwan is approximately 3 Mtoe, representing approximately 40% of total RE potential.

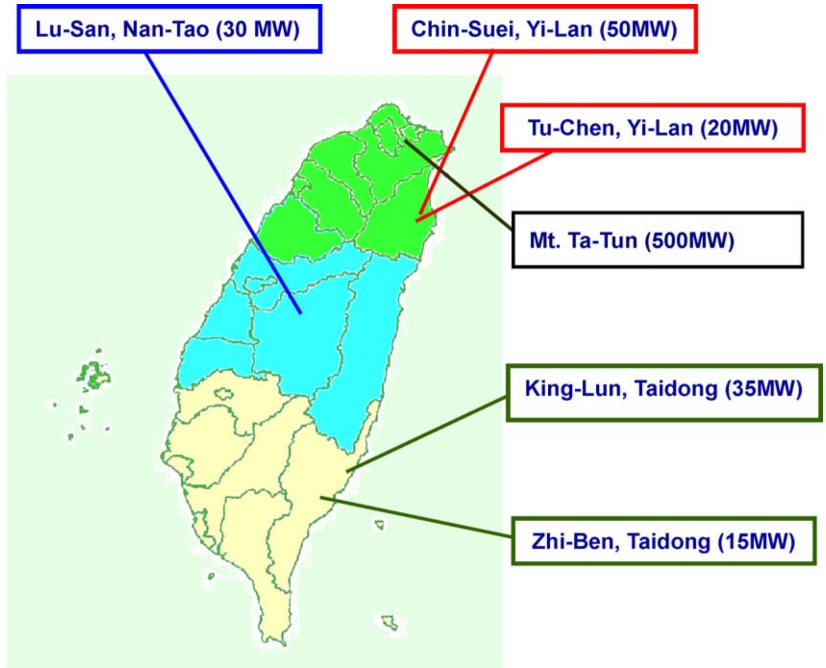
According to statistical analysis conducted in 2009, the electricity generation and thermal application potentials from domestic waste are approximately 28.6 TWh and 15 million tons/year, respectively. Both energy productions account most supply of the national renewables. As shown in Table 6, the main biomass energy resources are landfill gas and waste incineration, which have total electricity generation capacity of 602,200 kW (at the end of 2009) in more than 70 installed sites. Furthermore, a "Waste Energy Application Technology Development and Promotion Project" was initiated from 1999, in which the priorities of RD&D are waste energy applications, such as landfill gas, gasification, liquefaction and refuse derived fuel (RDF). In the factory of President Enterprises in Southern Taiwan, there are two electricity generation systems that utilize industrial wastewater (methane), and the installed capacity of each system is 80 kW. Meanwhile, the technical development of RDF is gradually matured. Solid RDF made from waste has the following advantages: high thermal value, uniform-and-stable property, ease of control and low pollution when burning, ease of transportation and storage, able to be used in boilers of power generation and co-generation, small environmental impact, high energy recycling efficiency, *etc*. RDF technology currently has been transferred from EEL to industry to establish factories to convert ordinary waste into useful fuel. Furthermore, a demonstration urban RDF system was established in EEL for the purposes of research and promotion. On the other hand, technologies of waste liquefaction and gasification have also been developed to convert waste into compound fuel or syngas (e.g., H_2, CO, and CH_4, *etc*.) that may be provided as the fuels of boiler and generator to generate steam and electricity, such that the goals of environmental protection, waste self-management and clean production may be fulfilled. Presently, specific technologies of solid waste energy have been developed successfully in EEL, for example rice husk gasification and waste Styrofoam liquefaction, which have been granted as patents and transferred to industry.

Regarding biodiesel, Taiwanese government has continuously pushed several promotion projects of biodiesel application since 2006, for example, Green Bus Project and Green County Project. Implementation of B1 was initiated since 2008, encouraging industry to invest the establishment of biodiesel factories. Currently, MOEA has approved 10 manufacturers annually producing 105,000 kl of biodiesel mostly from waste cooking oil. In the future, more aggressive promotion of goals will focus on developing more advanced technologies, including alcohol gasoline, organic hydrogen production, energy crop, forest resource, biodiesel, *etc*.

8. Geothermal energy

Taiwan lies on a major geological fault-line along the Pacific Rim, and has abundant geothermal resources, as shown in Fig. 5. A comprehensive exploration estimates that Taiwan has total geothermal potential of up to 1000 MW. However, most of the geothermal resources in Taiwan are located in remote areas, making their exploitation difficult. The economically and technically feasible exploitation potential is only about 150 MW. The target for geothermal utilization is 50 MW by 2010.

Unlike solar energy and wind power, the application of geothermal energy is not influenced by weather conditions and its stable output can provide a base load for power generation. Nowadays, the main application of geothermal energy is electricity generation, the cost of which is still higher than that of traditional generation methods. However, following electricity generation, the remaining hot water may be further utilized for multiple functions, including recreational spas, swimming pool, greenhouse horticulture and agriculture, air conditioning and so on, thus extracting additional economic value from the process. On the other hand, to avoid the gradual depletion of geothermal resources due to excessive extraction, most hot water after being used may be injected back to geothermal reservoirs, thus prolonging the operating life of the resource.



Site Name	Temperature Range (℃)	Electric Potential (MWe)
Chin-Suei, Yi-Lan	180-220	61
Tu-Chen, Yi-Lan	160-180	25
Lu-San, Nan-Tao	150-210	41
Zhi-Ben, Taidong	140-200	25
King-Lun, Taidong	140-180	48
Mt. Ta-Tun	200-290	514

Fig. 5. Geographical distribution and exploitation potential of geothermal resources in Taiwan [5].

Geothermal resources can be classified into volcanic and non-volcanic types, with the former being hotter but more acid than the latter. Domestic geothermal resources are mostly non-volcanic, and are located in mountains and on small islands, making access difficult. Geothermal resources with easy access and high potential will be prioritized for development. The most promising one is the Chin-Suei geothermal energy project (located at Yi-Lan County, as shown in Fig. 5), which will be developed by the local government using a BOT (Build, Operate, and Transfer) method, and for which technical planning and research will be provided by experienced R&D groups authorized by BEMOEA. Besides electricity generation, the hot water will be further utilized to make the project become a demonstration system with multiple functions.

9. Hydropower

Presently, most hydropower plants with large water dams are operated by the Taiwan Power Company. At the end of November 2009, the total installed capacity of hydropower in Taiwan was approximately 1937 MW, of which 1745 MW is contributed by plants with capacity exceeding 20 MW (excluding 2600 MW pump storage hydropower). According to a survey, Taiwan has about 5000 MW of technically feasible hydropower potential, about half of which is considered economically viable. Hopefully around 2500 MW can be exploited by 2020, with approximately 300 MW being small hydropower (SHP) plants, each with capacity of less than 20 MW; that is, they can be considered renewable energy, for example, flow-through type hydropower. Currently, the total installed capacity of operational SHP plants is around 166 MW.

In Taiwan, the application of large-scale dam is concentrated in agricultural irrigation and domestic water supply, with electricity generation generally regarded as an auxiliary use. For example, during 2008, the total generation output of hydropower in Taiwan was just 7772 million kWhs, equivalent to 1772 h of full-loading time. That is, the full-loading efficiency of hydropower in Taiwan is only 20.2%, much lower than the 60–70% average efficiency of nuclear or fossil fuel electrification. Most of the cost of hydro plant establishment goes to civil engineering for dam construction. Furthermore, most plants are located in remote mountain areas, which have high development costs and investment risks. However, a large-scale hydropower plant may have a useful lifetime of over 30 years, something unachievable by other generation methods. Considering the benefits in terms of both water supply and electricity generation, large-scale hydropower plants are actually the cheapest renewable energy option.

Hydropower is a clean, indigenous energy resource. However, due to disputes involving the ecological and environmental issues created by large-scale dam construction, the development of large-scale hydropower is inevitably difficult. However, SHP plants are also worth developing, and besides having less environmental impact also offer such advantages as short set-up time, easy maintenance, and low investment and operational costs. In Taiwan, most SHP resources are located in national parks, so careful evaluation is necessary and solutions must be sophisticatedly prepared before exploring and exploiting these resources.

Table 7
Current incentive measures for the promotion of renewable energy in Taiwan.

Type	Incentives	Current status [13,18]
Solar Water Heater (SWH)	Solar water heater (system) subsidy program Subsidy: NT$ 2250/m^2, based upon collector installed area	Total accumulated area of solar collector installed: 1,780,000 m^2 Energy saving: 0.086 Mtoe/year Industrial annual yield: NT$ 1.2 billion/year Total cumulated industrial yield: NT$ 18 billion CO_2 emission reduction: 0.62 million tons/year
Solar PV	Solar PV System Demonstration Program Subsidy: NT$ 150,000/kWp Subsidy ceiling: 50% of installation cost	There are over 400 demonstration projects with installed capacity of 6.7 MW (November, 2009)
Geothermal	Geothermal Energy Demonstration Program Subsidy ceiling: 50% of exploration costs	MOEA is currently sponsoring Ilan County to build a geothermal plant. Preliminary planning shall be a 5000 kW demo project (depending on exploration outcome)
Electricity Purchase Program	Tai-power Renewable Energy Premium Purchase Program	Fixed feed-in tariff is NT$ 2/kWh The approved capacity has reached 99 MW Total purchase capacity will be 600 MW
Tax Incentives	Statute for Upgrading Industries	Business entities investing in new and clean energy can enjoy tax credit no more than 11% of equipment costs
	Business Entities Purchasing Energy Saving Equipment or Using New Energy Equipment or Technology Investment Tax Credits	Investing in new and clean industry energy can enjoy income tax credit, ranging from 10% to 20% of stock purchase price Two-year's accelerated depreciation Low interest rate loans: no more than 2-year postal floating saving interest rate, plus 2.45%
	Customs Duty	Duty Exemption for imported equipment without manufacturing domestically

Note: 1 USD = 32.5 NTD.

10. Strategy developed and future perspectives

The current promotional measures are summarized in Table 7. Notably, the fixed feed-in tariff adopted by the Taiwan government is NT$ 2/kWh (equivalent to EUR 0.04/kWh), which is well below the average level in the EU [23], because the domestic electricity rate is only approximately EUR 0.05/kWh, making it extremely cheap internationally, which may be why relatively expensive RE electrification apparatus, especially solar PV system, is difficult to deploy in Taiwan, while cost-competitive wind power is relatively popular.

The backbone of the strategy for promotion of renewable energy formulated by the BOE is to create a favorable developmental environment to achieve the scheduled targets, and to facilitate the deployment of renewable energy apparatus in Taiwan while foster the establishment of local related industries. In addition, in order to iron-out and remove non-technical barriers, the "Renewable Energy Promotion Plan" (REPP) was drafted and approved by the Executive Yuan in January 2002. There are eight guiding strategies:

(1) to establish a higher level inter-ministerial coordinating mechanism,
(2) to draft and push for the passage of "Renewable Energy Development Bill" (REDB) and related regulations,
(3) to set up a favorable fixed feed-in tariff for renewable powers,
(4) to provide tax and investment incentives,
(5) to provide sufficient interim budget and funding,
(6) to increase demonstrations and promotional activities,
(7) to establish renewable energy database, and
(8) to enhance RD&D in renewable technology and products.

Being coupled with these strategies are 24 promotional measures. The REPP coordinates actions by 13 central government ministries and local government agencies, with the following five main focal points:

(1) Demonstrations and promotional measures: several incentive measures have been instituted as interim means to subsidize renewable energies (see Table 7).
(2) Tax and investment incentives: according to "Statute for Upgrading Industries", the business entity that invests RE apparatus is preferentially provided with tax credit no more than 11% of equipment costs, income tax credit ranging from 10 to 20% of stock purchase price, low interest rate loans and 2-year's accelerated depreciation.
(3) R&D for renewable energies: to develop highly efficient, low cost and mass-producible renewable energy application technologies and products.
(4) Coordinating mechanism: through a high-level inter-ministerial coordinating mechanism, all institutional non-technical barriers encountered by renewable energy developers are facilitated and resolved in a systematic manner.
(5) A fixed feed-in tariff: an interim measure to purchase renewable power at NT$ 2/kWh ($\sim$EUR 0.04/kWh) has been approved by state-owned Tai-Power company up to 600 MW.

As shown in Fig. 6, according to the framework and contents of "Renewable Energy Development Bill" drafted by Executive Yuan, the essence of promotion strategies for renewable energies in Taiwan can be summarized as follows.

(1) In the medium term, the renewable energies shall contribute 10%, in terms of installed capacity by 2010.
(2) Wind technology is relatively mature and will be the major renewable energy in the near term. Meanwhile, the government shall continue to promote other renewable energies such as geothermal, biomass and hydropower to utilize renewable resources in all aspects.

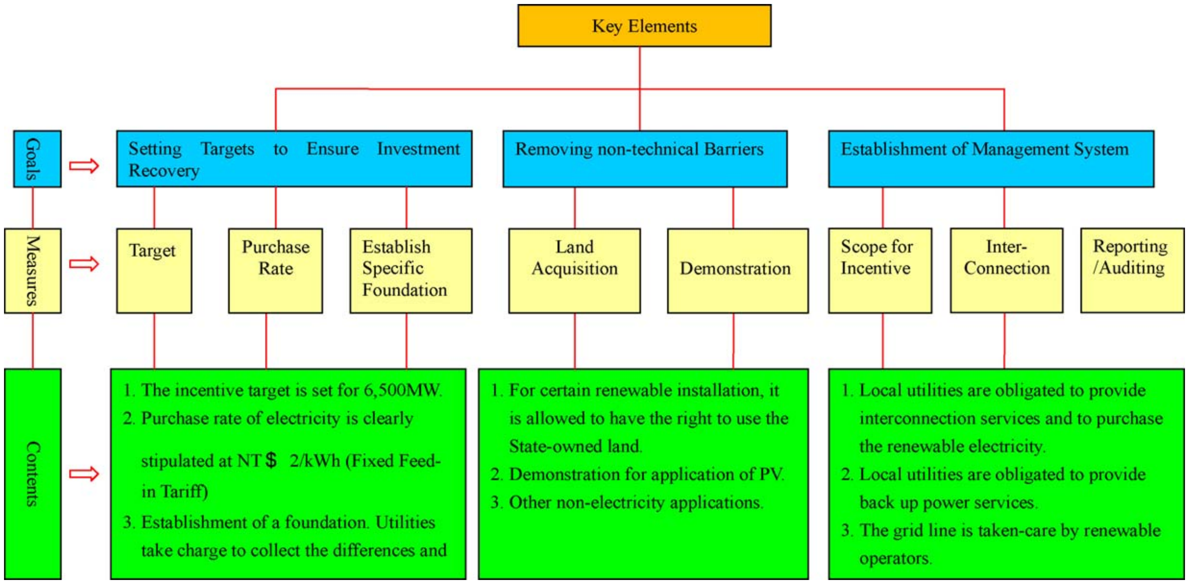


Fig. 6. Framework and contents of renewable energy development bill [13].

(3) Solar photovoltaic (PV) product is booming in current energy market worldwide. The promotion of PV shall focus on strengthening R&D capability and developing related industries for cost reduction.
(4) In the long term, the ratio of renewable energy to total energy supply is projected to increase from 1% in 2003 to 4% in 2020.

Developing renewable energy in Taiwan not only can secure national energy supply but also can achieve environmental protection and sustainable management objectives. Planning of domestic renewable energy development follows four stages: research, demonstration, promotion, and prevalence. To summarize, current strategies for developing major renewable energies in Taiwan are as follows.

(1) Solar thermal energy – incentive and promotional phase;
(2) Photovoltaics – incentive and demonstration phase;
(3) Wind energy – promotional phase;
(4) Biomass energy – researching and demonstration; and
(5) Geothermal energy – promotional phase.

Furthermore, through the ‘‘Renewable Energy Development Plan’’, a negotiating mechanism is established among higher governmental levels, and it is expected that non-technical barriers will be removed, leading to the creation of a more advantageous circumstance. In the future, according to the ‘‘Renewable Energy Development Bill’’, regulations and legislation will be introduced regarding related issues, including fixed feed-in tariffs, grid connection standards and subsidy systems.

11. Summary and conclusions

Taiwan is an island nation with limited indigenous conventional energy resources, but enjoys abundant resources of renewable energy as described above. Developing renewable energy not only can enhance energy supply security, while simultaneously promoting environmental protection values, but also can boost economic development. Following the global trend towards sustainable development, developing renewable can help Taiwan succeed in three aspects, namely, energy supply, economic progress, and environmental protection. Currently, Taiwan has begun pursuing renewable energy development, whether in terms of domestic implementation or relative industry. However, the share of renewable energy of total energy supply remains minor, and considerable room remains for development. The key issue in RE strategy is the passage of ‘‘Renewable Energy Development Bill’’, which had just been approved by the Legislative Yuan in June 2009. In the near future, it is expected that renewable energy will be competitive in the Taiwanese market. However, from another perspective, implementing RE may not be totally appropriate in Taiwan, but the related industrial development offers positive economic benefits, which has been described in the forgoing, such as solar thermal energy, photovoltaics, and wind energy, all of which have formatively industrial bases in Taiwan already.

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